NUWC-NPT Technical Document 10,451
21 September 1993

A Survey of the Impact on Acoustic Propagation of Warm Core Ocean Eddys

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PREFACE

This work was accomplished under NUWC Project No. A62200, the Shallow Water Sonar Initiative (SWSI), P. D. Herstein, Principal Investigator. The SWSI is part of the Surface Ship ASW Advanced Development Program (SASWAD), B. Cole, NUWC Program Manager. This work was sponsored by E. Plummer, PEO USW ASTO B.

Reviewed and Approved: 21 September 1993

D. W. Counsellor
Associate Director for
Surface Antisubmarine Warfare

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)

2. REPORT DATE

21 September 1993

3. REPORT TYPE AND DATES COVERED

Final

4. TITLE AND SUBTITLE

A Survey of the Impact on Acoustic Propagation of Warm Core Eddys

5. FUNDING NUMBERS

E64600

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Undersea Warfare Center Detachment
39 Smith Street
New London, Connecticut 06320

8. PERFORMING ORGANIZATION REPORT NUMBER

TD 10,451

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Program Executive Officer
Undersea Warfare
Washington, DC 20350-1000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

A

13. ABSTRACT (Maximum 200 words)

Warm core eddys have been found throughout the oceans of the world. Most have a bowl-like shape extending down from the surface, which, along with an increased sound speed due to the warmer water core, causes more acoustic energy to be refracted toward the surface than would occur without an eddy present. However, the impact on acoustic propagation varies significantly from ocean to ocean, because of variations in eddy size and core temperature, as well as sound speed profile differences in the adjoining waters. Examples are given from the North and South Atlantic Oceans, North and South Pacific Oceans, Greenland and Norwegian Seas.

14. SUBJECT TERMS

Shallow Water, Optimum Frequency, Source-Receiver Placement, Environmental Dependance Tracking, Environmental Acoutics

15. NUMBER OF PAGES

20

16.

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

A SURVEY OF THE IMPACT ON ACOUSTIC PROPAGATION OF WARM CORE OCEAN EDDYS

INTRODUCTION

This technical document contains material of the presentation 022C-9 given at the poster session 022C, "A Survey of the Impact on Acoustic Propagation of Warm Core Ocean Eddys," at the Fall 1992 meeting of the American Geophysical Union held at San Francisco, CA, on Tuesday, December 8, 1992.

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A SURVEY OF THE IMPACT ON ACOUSTIC PROPAGATION OF WARM CORE OCEAN EDDYS

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JMM 11/13/92 VG 1

VISUAL 1

To do a survey on the acoustic impact of warm core eddys in 15 minutes is, indeed, like trying to stuff 10 pounds in a 5 pound bag. But I believe that we can illustrate the important points and, because most of this work is ours, provide further details later for anyone who wants them.

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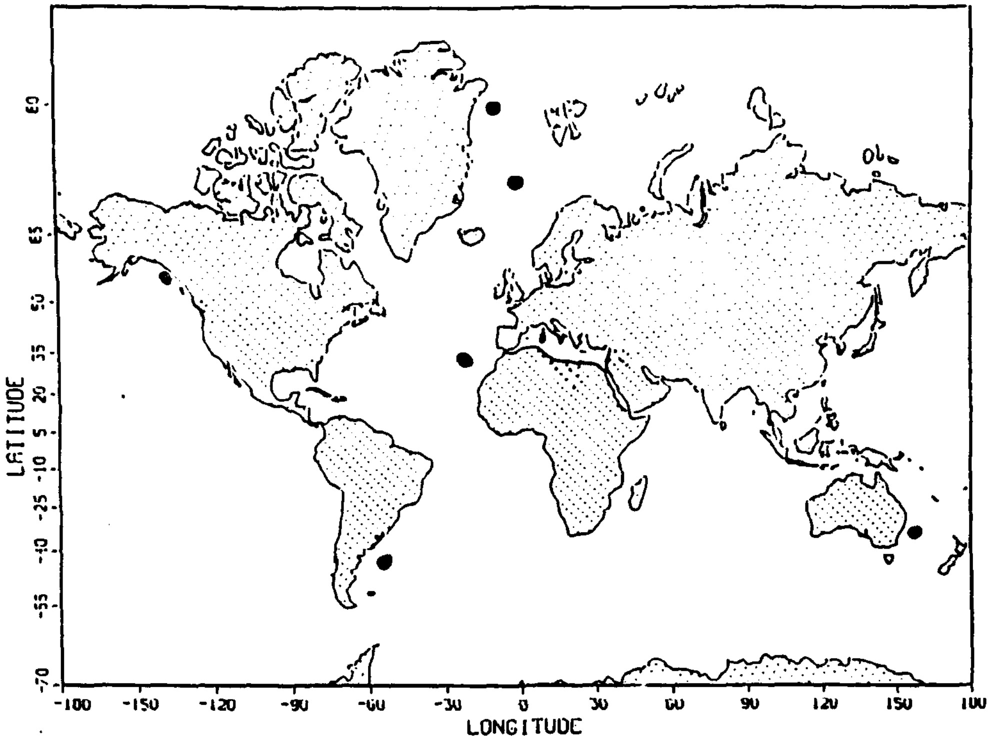

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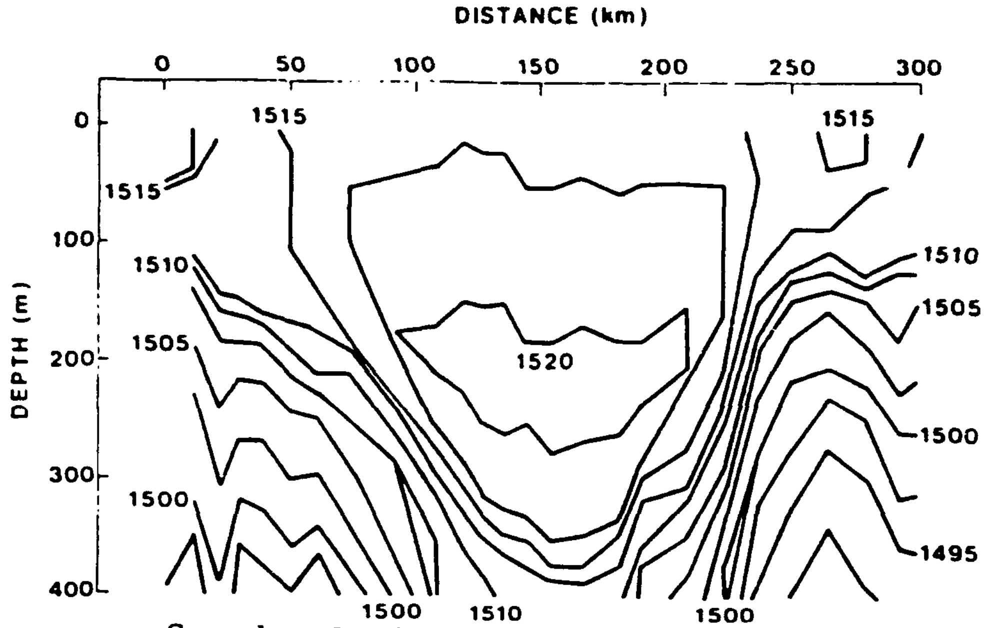
VISUAL 2

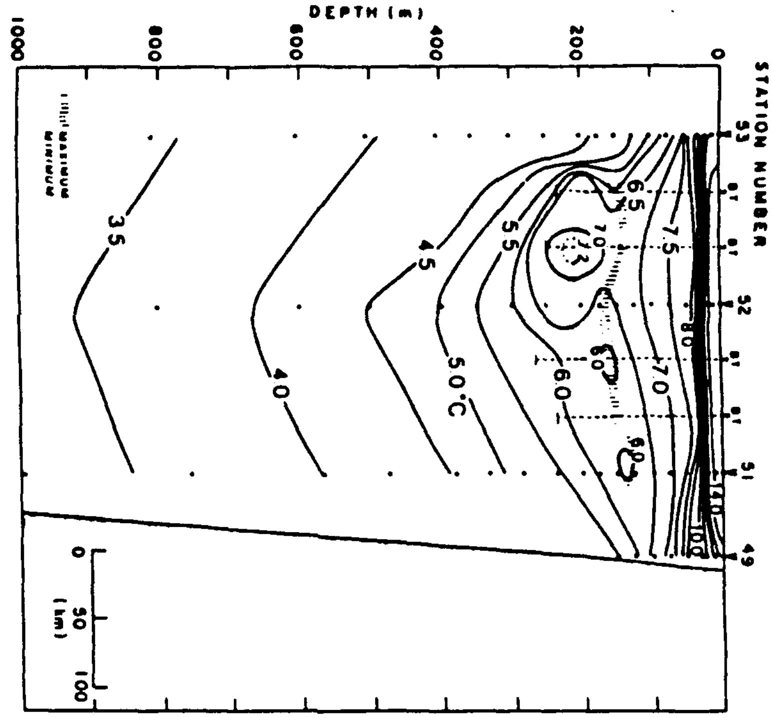
Warm core eddys appear to be found worldwide. Shown here are the eddys that we have analyzed ranging from Australia to Greenland. As we have already seen in this session, there are other locations, such as the Agulhas Eddys. Many occur in important shipping lanes, so, in practical terms, warm core eddys cannot be ignored.



Sound velocity cross section of a warm core eddy (isovels are in m sec^{-1}).

VISUAL 3

Here we have a sound speed cross-section for an eastern Australian current eddy under winter conditions. From the lens-like structure you can see why eddys demand the attention of acousticians. Warm core eddys are of special interest to us because they are generally located near the surface; this eddy has a large surface expression and therefore will significantly impact surface ship sonars.



VISUAL 4

All eddy data are not quite as neat, as shown by temperature cross section of the North Pacific "Sitka" eddy here. Many eddys during summer conditions are covered by a warmer water veneer which will alter the propagation conditions. One practical problem is that, in hindsight, many environmental measurement sections taken are not along an exact diameter of the eddy.

Still, they all retain a lens-like shape which can alter the acoustic field. It should be noted that "warm core" is a relative term, and to some extend the acoustics depend on the absolute temperatures.

ACOUSTIC SIMILARITIES OF WARM CORE EDDYS

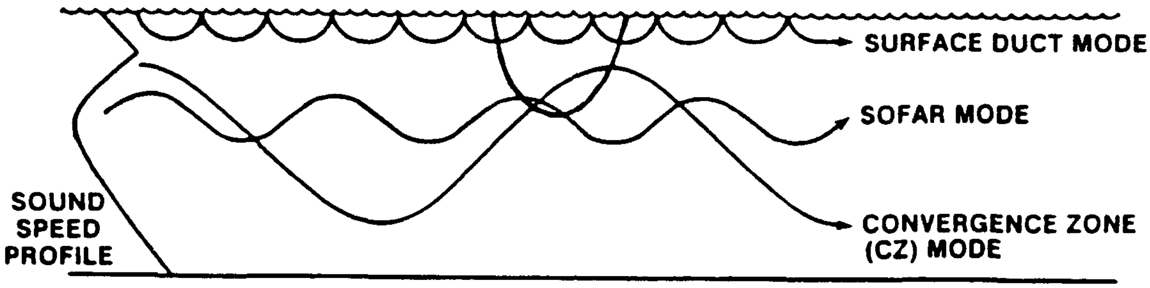
- LENS (CANONICAL) SHAPE
- INCREASED SOUND SPEED
- SURFACE (SEASONAL) EXPRESSION (EXCEPT MEDDIES)
- ADJACENT WATER HAS DEEP SOUND CHANNEL (DSC)

JMM 11/12/92 VG 2

VISUAL 5

From one acoustician's point of view we can summarize the common traits we have found in these warm core eddys. First, they all are acoustic lenses. Because sound speed increases with temperature, they are regions of higher sound speed. They tend to be located near the surface and have a surface expression at least part of the year; one exception are the deeper Mediterranean water eddys (Meddies) in the North Atlantic. Finally, they all have a deep sound channel in the water adjacent to them. The depth of the sound channel axis, relative to the location of the eddy, is very important in the acoustic propagation in and out of an eddy.

ACOUSTIC PROPAGATION MODES



VISUAL 6

Unfortunately, the term mode is used several ways in underwater sound. Here we use it to specify different types of acoustic propagation. For a typical deep ocean sound speed profile, there are three main modes of long range sound propagation: surface duct propagation; sound channel axis (or SOFAR) propagation; and convergence zone (CZ) propagation.

As you can see each could be impacted by a warm core eddy differently. Surface duct and CZ propagation, of greatest interest to us, have the greatest potential for change. In this case, SOFAR propagation should hardly be changed, but if the outside sound channel axis was shallower, the effect would be greater, so we must always consider the outside profile as well as the changing profiles in the eddy.

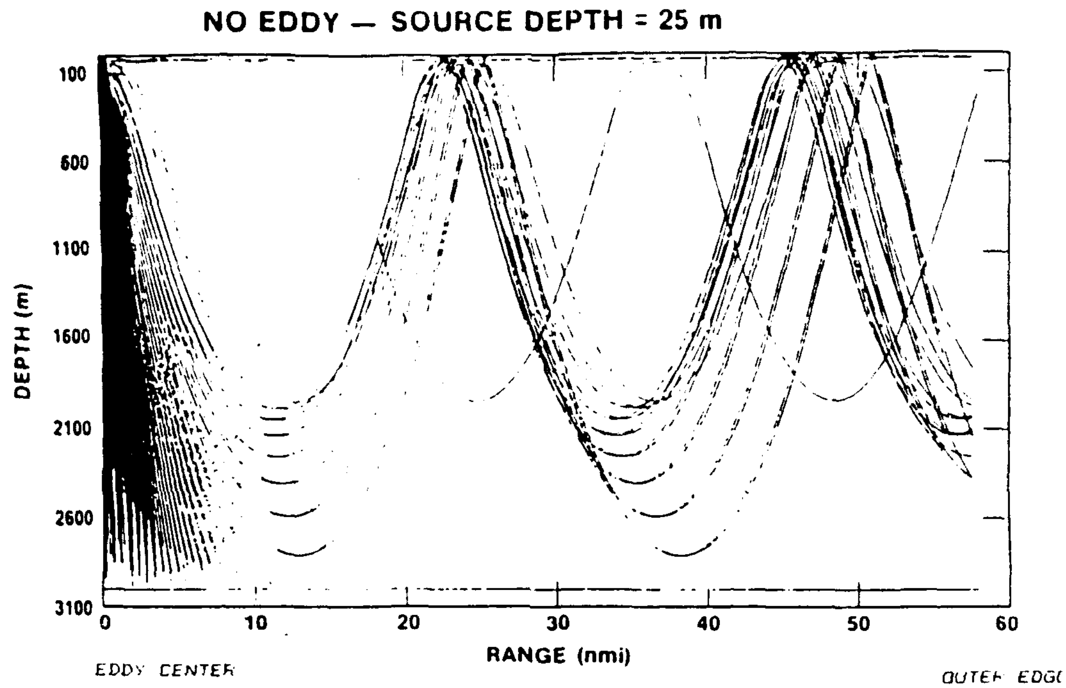
IMPACT OF WARM CORE EDDYS ON ACOUSTIC PROPAGATION

- TERMINATION OR INITIATION OF AN ACOUSTIC DUCT
- SHIFT IN CONVERGENCE ZONE (CZ) RANGE AND LEVEL
- ACOUSTIC TRAVEL TIME CHANGE (POSITIVE)
- RANGE DEPENDENT DUCT (TAPERED) LEAKAGE

JMM 11/12/92 VG 3

VISUAL 7

We have found four principal effects of warm core eddys on sound propagation: termination or initiation of acoustic ducts; a shift in convergence zone range and level; change in acoustic travel times; and finally, range dependent leakage from tapering acoustic ducts. We shall illustrate each of these conditions.

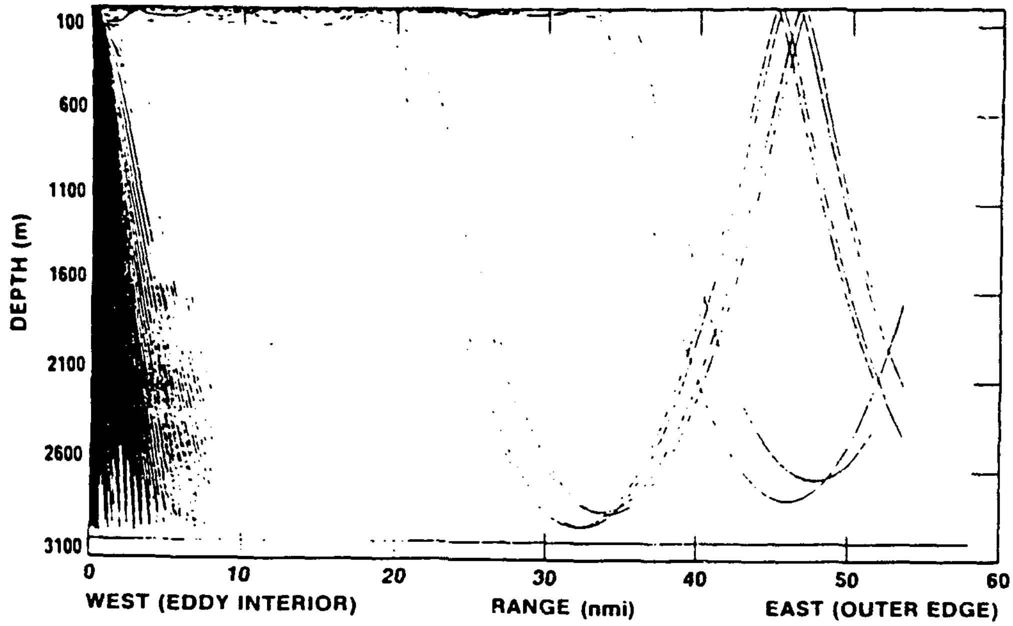


VISUAL 8

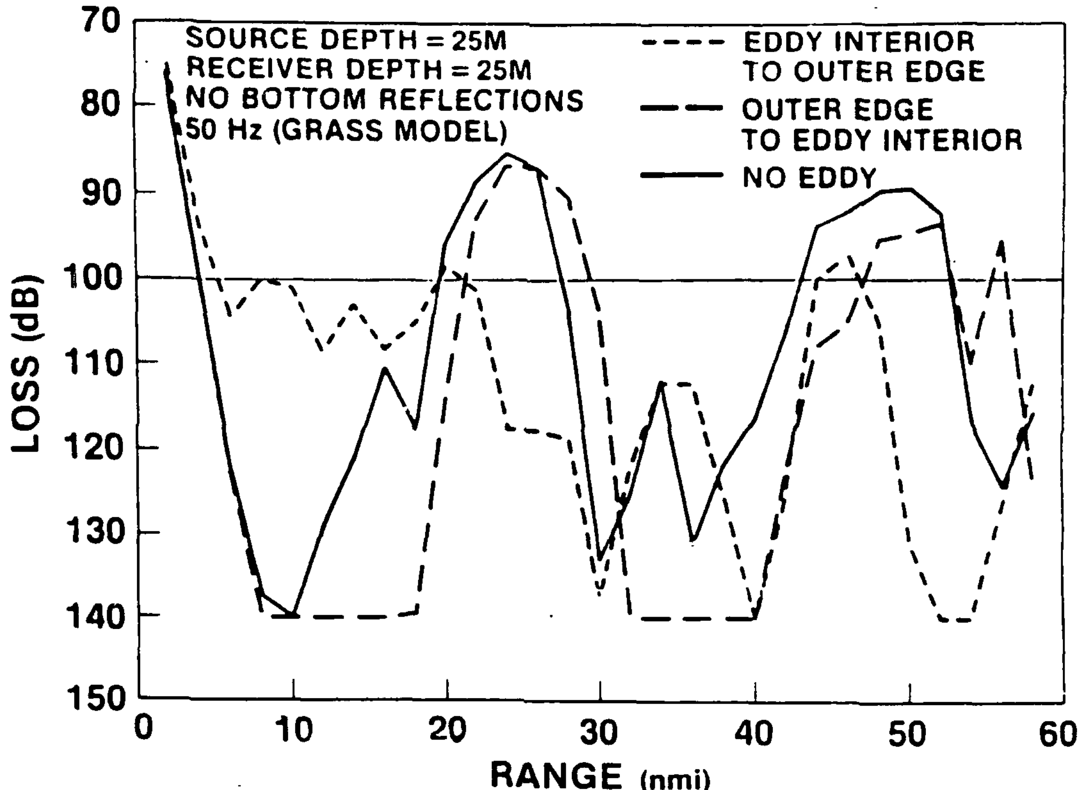
Perhaps the most striking effect is the sudden termination of a duct by an eddy, as shown in this ray diagram for a South Atlantic warm core eddy. As we mentioned before, we need the right source and receiver depths for this to be a principal propagation mode, but in this case, these are depths of practical importance, both source and receiver are at 25 meters depth. In this case we are propagating from the center of the eddy outward. Duct transmission, inherently without any bottom loss, is an efficient and desirable propagation mode where possible.

SOUTH ATLANTIC WARM CORE EDDY PROPAGATION FROM EDDY INTERIOR TO ITS OUTER EDGE

SOURCE DEPTH = 25 m



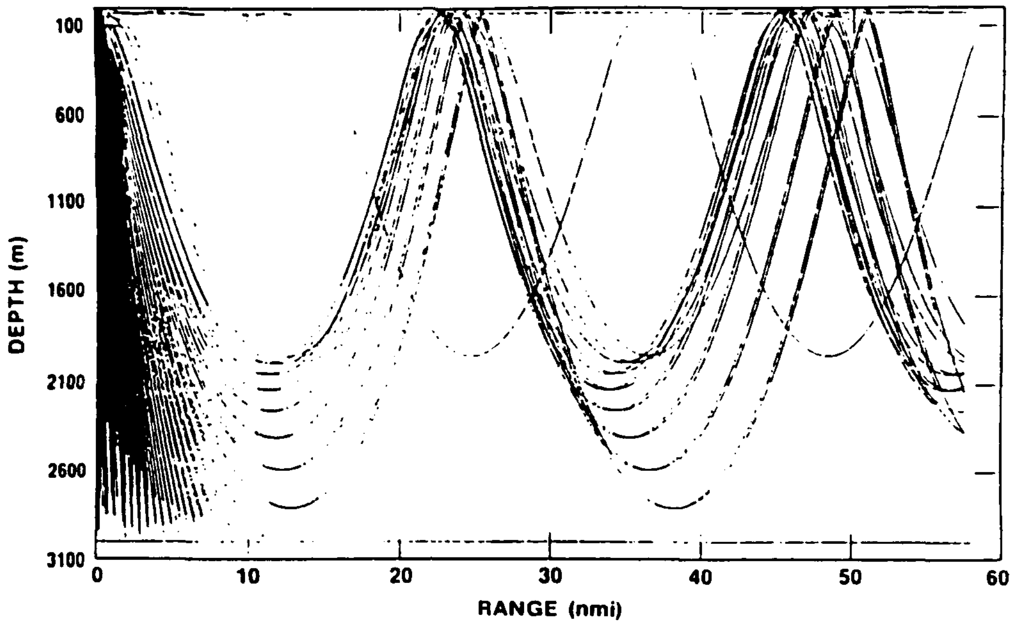
VISUAL 8 (OVERLAY)



VISUAL 9

The corresponding propagation loss as a function of range 3 at a frequency of 50 hertz is shown here. Our case is shown by the small dash line. The termination occurs at a range of 20 kilometers. Without the eddy (solid line) we would have convergence zone type propagation and you can see the considerable difference between the two cases. Also shown is the propagation from the edge of the eddy into the center (long dashs). It is also CZ type propagation and we will discuss the impact of eddys on convergence zone propagation next.

NO EDDY — SOURCE DEPTH = 25 m



VISUAL 10

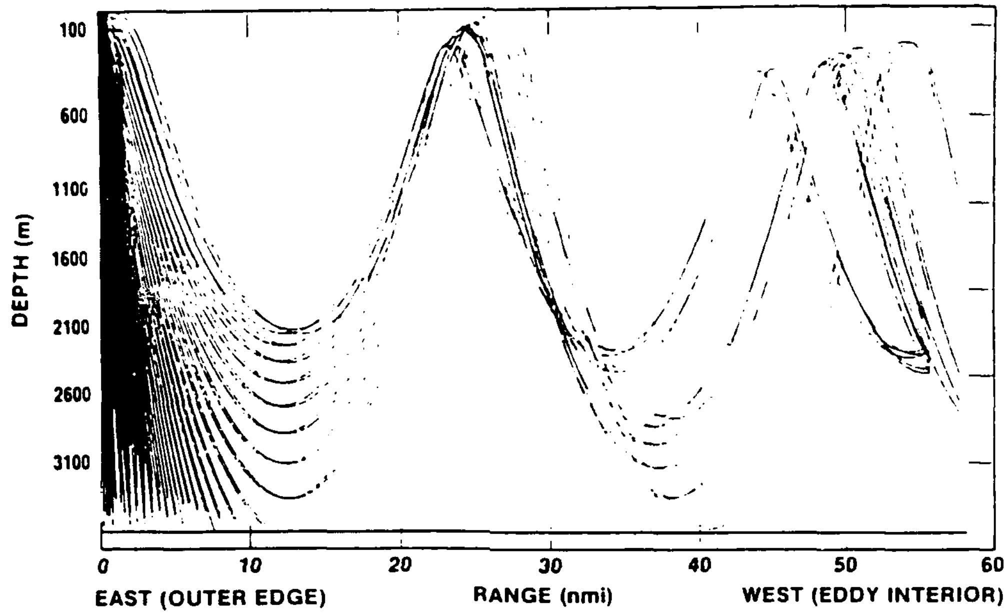
As shown previously, convergence zone propagation is common through eddys. For this mode, the placement of the source horizontally relative to the center of the eddy is more important than for the other propagation modes.

First we show the convergence zone propagation paths for a 25 meter source with no eddy present. It is possible, for example, that if the spacing were right, the ray paths could travel down underneath the eddy and turn upward relatively unperturbed.

For most configurations, however, the eddy does cause a significant shift in the range of the convergence zone compared to the case with no eddy. We show this by now overlaying the ray diagram that results when the eddy is present. We assume our source is at the edge of the eddy. You can see the shift in the ranges of the convergence zones, the first from 22 NMI to 26 NMI, etc. You can also see that the character has been changed especially in the second CZ, and that the vertex has been shifted down from the surface.

SOUTH ATLANTIC WARM CORE EDDY PROPAGATION FROM OUTER EDGE TO EDDY INTERIOR

SOURCE DEPTH = 25 m



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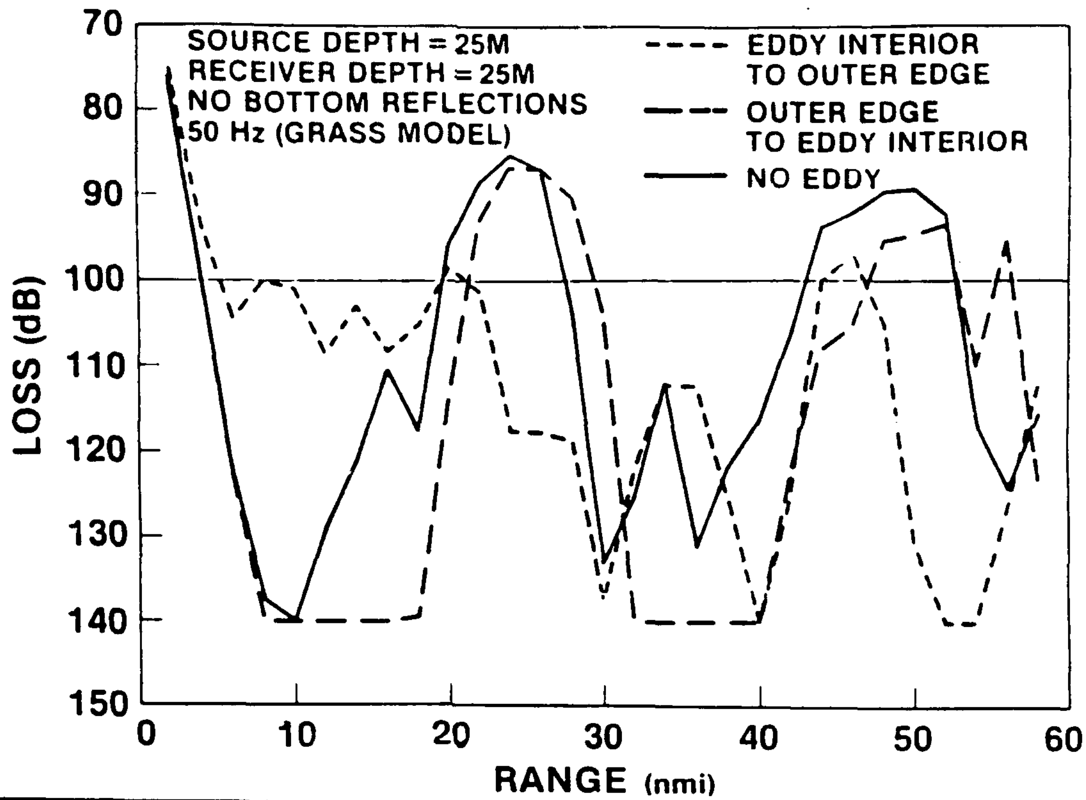
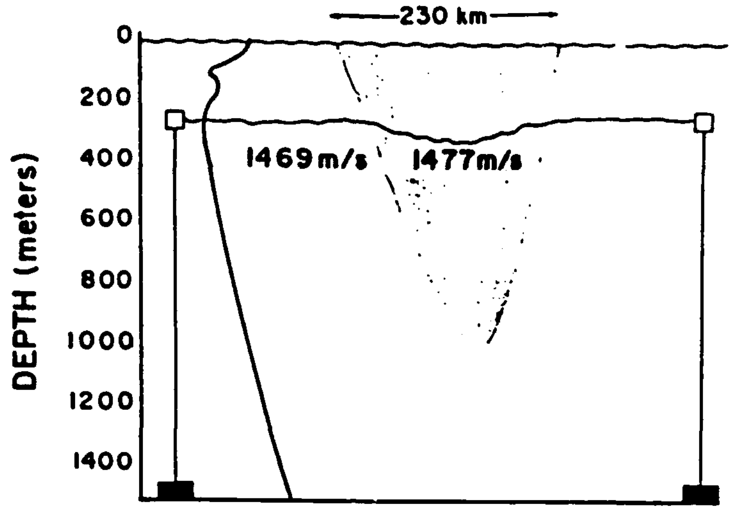
VISUAL 10 (OVERLAY)



VISUAL 11

Returning now to the previous propagation loss comparison, recall that the no-eddy case is shown by the solid line. We now compare with the eddy edge to center, shown by the long dash line. You can see both the range shift in the first CZ and energy reduction in the second CZ (actually, as the ray diagram showed, the energy is being shifted to a deeper depth by the warmer water refraction and you would see a corresponding increase for a deeper receiver).

APPLICATION TO TOMOGRAPHY



$$\Delta t = \frac{230 \times 10^3}{1469} - \frac{230 \times 10^3}{1477}$$

$$\Delta t = 156 - 155 = 1 \text{ sec.}$$
$$= 1000 \text{ msec.}$$

VISUAL 12

Another impact of the eddy is a change in acoustic travel times. As sound speed in seawater increases with temperature, one would generally expect a reduction of travel times in a warm core eddy. This could be complicated either way, of course, by changes in path lengths due to changes in refraction conditions. But here we have a rather spectacular example for the "SITKA" eddy. If the outside deep sound channel (DSC) axis were deeper, the change would not be as great and, unfortunately, this has been the case in most of the tomography experiments to date.

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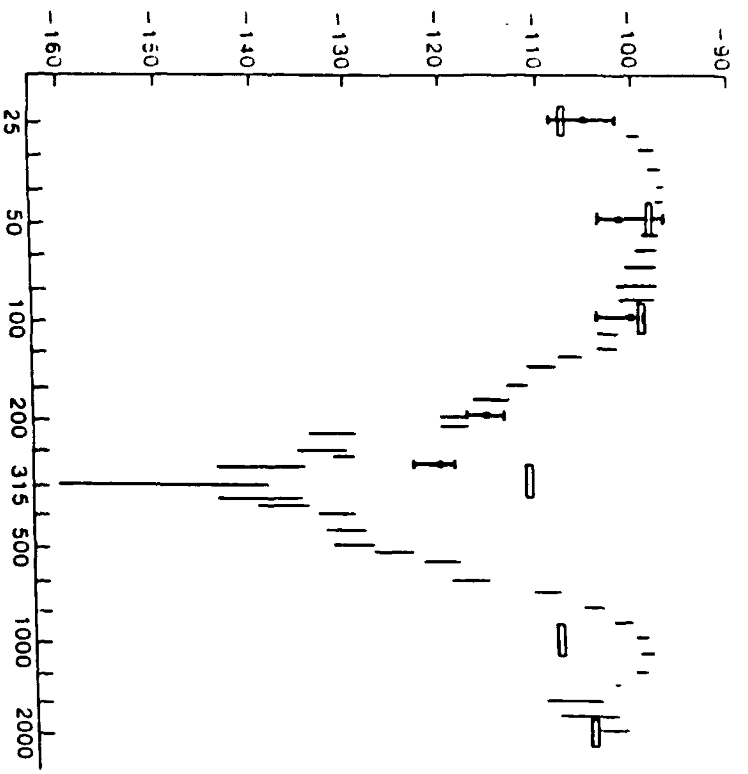

Spectrum of relative intensity in the eddy duct for an acoustic source in the surface duct over the range interval 14–15 km. Thin vertical lines: extent of the normal mode predictions over the range interval (from Hall[7]). Thick vertical lines: extent of the parabolic predictions over the range interval based on the Lee model.[8,9] Open boxes: experimentally measured data; the horizontal extent corresponds to the 1/3-octave bands recorded.

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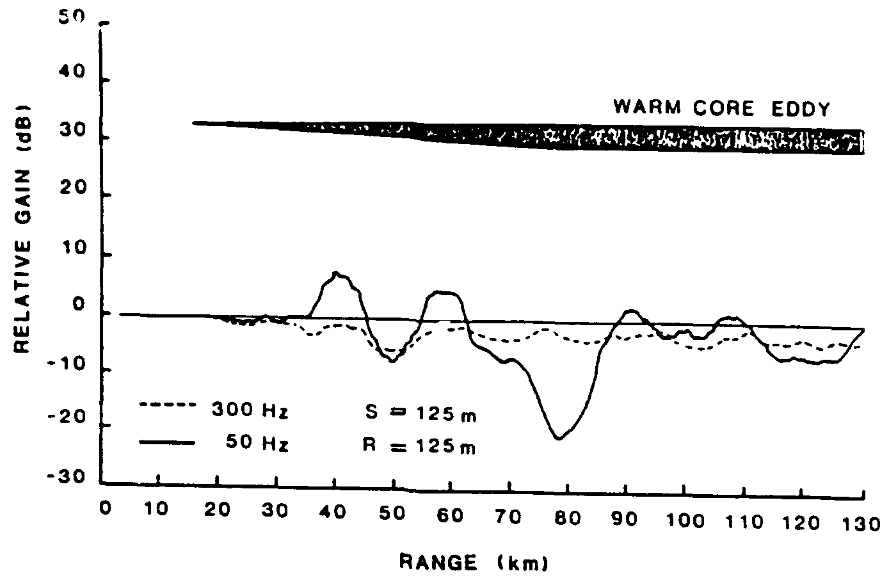
VISUAL 13

Due to the conical shape of the eddy, the acoustic ducts crossing them tend to be tapered. If the acoustic wavelength is not at all times small compared to the thickness of the duct, acoustic weakness will occur. Here we compare two frequencies (50 and 300 hertz) propagating from the edge into the center for the "SITKA" eddy with the propagation loss without the eddy. The difference is expressed as relative gain. You can see that the 300 hertz is always trapped, giving a uniform result. Fifty hertz, however, with a corresponding longer wavelength, is apparently sensitive to the duct thickness and there is considerable variation in the gain until the duct becomes thick enough near the center.



VISUAL 14

With an eddy, several tapered ducts may occur on top of one another. Needless to say, acoustically, this can become very complicated, but the important point is that optimum frequencies may occur, as shown here for the "ANZUS" eddy.

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ACOUSTIC IMPACT OF WARM CORE EDDYS CONCLUSIONS

- EDDYS PREVALENT IN SHIPPING ROUTES, CANNOT BE IGNORED
- WARM CORE EDDYS MOST IMPACT SHALLOW ACOUSTIC SENSORS
- ADJACENT WATER SOUNDSPEED PROFILES ARE A KEY FACTOR
- CHANGE IN SENSOR LOCATION RELATIVE TO EDDY CAN CHANGE ACOUSTIC IMPACT

JMM 11/12/92 VG 4

VISUAL 15

CONCLUSIONS

We can summarize as follows:

Acoustically speaking, eddys can't be ignored, and, of particular interest to us, are warm core eddys.

The impact on acoustic propagation is determined not only by the sound speed profiles in the eddy but also by their relationship to the profiles in the adjacent water.

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